



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 :  
H01Q 25/00, 3/24, 3/26

A1

(11) International Publication Number:

WO 88/08623

(43) International Publication Date: 3 November 1988 (03.11.88)

(21) International Application Number: PCT/US88/01319

(22) International Filing Date: 21 April 1988 (21.04.88)

(31) Priority Application Number: 043,406

(32) Priority Date: 28 April 1987 (28.04.87)

(33) Priority Country: US

(71) Applicant: HUGHES AIRCRAFT COMPANY [US/US]; 7200 Hughes Terrace, Los Angeles, CA 90045-0066 (US).

(72) Inventor: MIGLIA, EGIDIO ; 4253 Chaumont Road, Woodland Hills, CA 91364 (US).

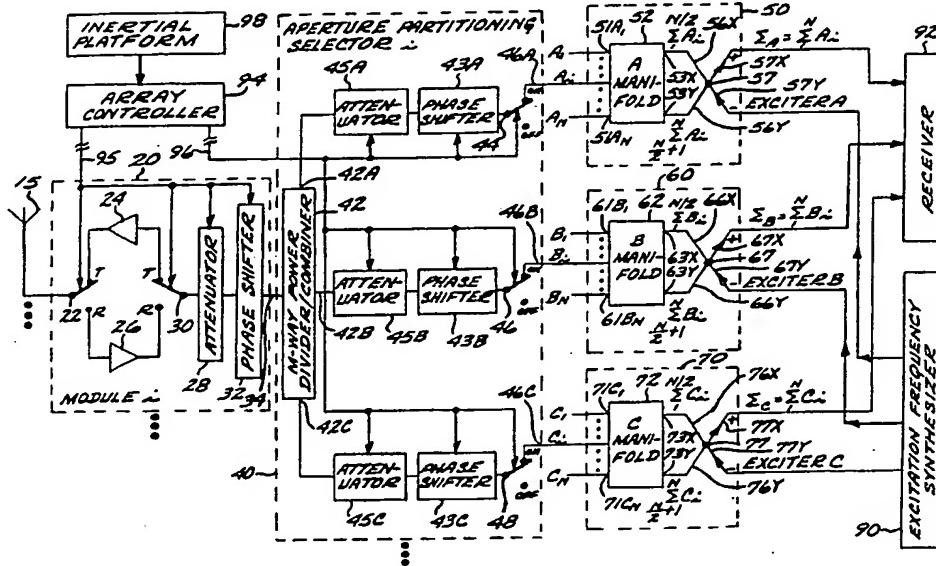
(74) Agents: ALKOV, Leonard, A. et al.; Hughes Aircraft Company, Post Office Box 45066, Bldg. C1. MS A126, Los Angeles, CA 90045-0066 (US).

(81) Designated States: DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, SE (European patent).

## Published

*With international search report.**Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*

## (54) Title: MULTIFUNCTION ACTIVE ARRAY



## (57) Abstract

A multifunction active array system is disclosed, wherein the array aperture may be partitioned into a plurality of arbitrary subapertures. The array system includes N radiative elements, each coupled to a corresponding active module. Each module is in turn connected to an aperture partition selector (40), which includes an M-way power divider/combiner device (42), having a module port (34) and M device ports. Each device port is coupled through an RF switch (46) to a partition port of the device. M N-way manifolds (52, 62, ...) are provided, having N manifold ports coupled to a respective one of said partition ports of each selector. The manifolds are coupled to a receiver (92) and an excitation source (90). Each partition may be formed by the desired connection of a particular module to a manifold by the respective positions of the RF switches. The array system provides the capabilities of partitioning the array into M or less subapertures to simultaneously generate sum patterns, difference patterns, guard patterns, and adaptive nullings. The partitions on receive and transmit are independent, and they may differ in an arbitrary manner. The subapertures may overlap.

***FOR THE PURPOSES OF INFORMATION ONLY***

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT Austria  
AU Australia  
BB Barbados  
BE Belgium  
BG Bulgaria  
BJ Benin  
BR Brazil  
CF Central African Republic  
CG Congo  
CH Switzerland  
CM Cameroon  
DE Germany, Federal Republic of  
DK Denmark  
FI Finland

FR France  
GA Gabon  
GB United Kingdom  
HU Hungary  
IT Italy  
JP Japan  
KP Democratic People's Republic  
of Korea  
KR Republic of Korea  
LI Liechtenstein  
LK Sri Lanka  
LU Luxembourg  
MC Monaco  
MG Madagascar

ML Mali  
MR Mauritania  
MW Malawi  
NL Netherlands  
NO Norway  
RO Romania  
SD Sudan  
SE Sweden  
SN Senegal  
SU Soviet Union  
TD Chad  
TG Togo  
US United States of America

1

**MULTIFUNCTION ACTIVE ARRAY**  
**BACKGROUND OF THE INVENTION**

1           The invention relates to techniques for electronically varying the partitioning of planar arrays or phase scanned arrays into sub-arrays or subapertures.

5           In many airborne radar modes, in particular the terrain following and terrain avoidance modes, difference patterns stabilized with respect to the horizon are required. The technique generally used to generate sum and difference patterns in gimballed planar arrays or phased scanned arrays is to partition the array into quadrants with a separate output for each quadrant. The appropriate quadrant outputs are summed or differenced to provide a sum pattern and two difference patterns. The two difference patterns provide tracking error signals referenced to the antenna.

10           Conventional solutions to the problem of providing roll stabilized sum and difference patterns in airborne radars include providing a third gimbal or implementing rather cumbersome and not entirely satisfactory signal processing to derive roll stabilized tracking outputs. The roll gimbal technique is probably not feasible for active array systems of sufficient size to require liquid cooling. An alternative to the signal processing approach is needed.

25           It would therefore represent an advance in the art to provide an active array which can be electronically roll stabilized without the need for mechanical roll gimbals or cumbersome signal processing.

1        It would further be advantageous to provide a multifunction active array which may be electronically configured into a plurality of arbitrary sub-arrays or subapertures.

5                          SUMMARY OF THE INVENTION

A multifunction active array system is disclosed, wherein the system aperture may be programmably subdivided into a plurality of subapertures. The array system comprises N radiative elements connected to N active modules. Each module is universal in the sense that each comprises the same elements.

10        Each module is in turn connected to an aperture partitioning selector, which includes an M-way power divider/combiner device. This device functions, in the receive mode, to divide the module receive signal into M components. In the transmit mode, the device functions to combine up to M excitation signal sources and couple the combined excitation signals to the module for amplification and radiation by the radiative element.

15        Each aperture partitioning selector further comprises M RF switches for coupling the respective ports of the M-way power divider/combiner device either to an "off" position or to an "on" position at a partition port.

20        The system further comprises M manifold apparatus having N selector ports, the corresponding partition ports of each aperture partitioning selector being connected to the N selector ports. Each manifold comprises an N-way power combiner/divider device, so that in the receive mode, the signals at each of the corresponding partition ports are summed. Thus, the selector provides the capability of selection of those radiative elements and modules whose receive signal contributions are combined in a particular one of the M subapertures. In the transmit sense, the manifold apparatus and partitioning selectors provide the capability of dividing M or less excitation

1 signals into N components and providing a component to the selected ones of the modules for amplification and subsequent radiation.

5 The active array system may be configured to achieve one or more functions without making hardware changes. The array aperture can be partitioned into M or fewer subapertures. The subapertures can overlap and the aperture partitioning in the receive and transmit modes can differ in any arbitrary manner. Each subaperture can 10 transmit and receive at different frequencies and scan angles. The system can provide sum, differences and guard patterns, adaptive nulling, off-broadside expanded bandwidth for large size apertures, and roll stabilization for all modes.

15

#### BRIEF DESCRIPTION OF THE DRAWINGS

20

These and other features and advantages of the present invention will become more apparent from the following detailed description of an exemplary embodiment thereof, as illustrated in the accompanying drawings, in which:

FIG. 1 is a simplified functional block diagram, for  $M = 3$ , of a multifunction active array system embodying the invention.

25

FIG. 2 is a functional diagram illustrative of an array system as in FIG. 1 with a circular aperture, showing the division of the aperture into four quadrants for generating simultaneous sum, azimuth difference, and elevation difference patterns.

30

FIG. 3 is a diagrammatic depiction of roll stabilized array quadrants for providing azimuth and elevation difference patterns.

FIG. 4 is a functional diagram illustrative of an array system as in FIG. 1 with a circular aperture, showing the generation of an auxiliary aperture for

1 adaptive nulling and simultaneous sum and azimuth difference patterns.

5 FIGS. 5A and 5B are functional diagrams illustrative of an array system as in FIG. 1 with a circular aperture, showing two possible overlapped aperture partitions.

DETAILED DESCRIPTION OF THE DISCLOSURE

10 Referring now to FIG. 1, a block diagram of a multifunction active array system embodying the invention is disclosed. As will be understood by those skilled in the art, the array comprises a plurality of radiative elements 15, each coupled to a corresponding active module 20. For clarity, only the "i"th element 15 and module 20 are shown in FIG. 1, where i is an index varying from 1 to N, and N represents the total number of modules. Each of 15 the modules comprising the array is identical to the universal module 20 of FIG. 1.

Module 20 comprises a beam steering phase shifter 32 and a variable RF attenuator 28. These two devices may be connected either to the transmit channel comprising transmit amplifier 24 or to the receive channel comprising low noise amplifier 26 by RF switch 30. RF switch 22 connects either the receive channel or the transmit channel to the radiative element 15. The RF switches 22 and 30 are controlled by the array controller 94 to select either the module transmit channel when an excitation signal is provided to the module 20 or the module receive channel when the module 20 is selected to provide an amplified version of signals incident on the radiative element 15. In operation, the RF switches 22 and 30 are both either in the transmit "T" position or in the receive "R" position. The functions of these switches could alternatively be accomplished by RF circulator devices, well known to those skilled in the art.

35 The beam steering phase shifter 32 preferably is digitally controlled by controller 94, and introduces the

1 phase shift necessary to steer the aperture beam in the  
desired direction, as is well known to those skilled in  
the art.

5 The variable attenuator 28 is also controlled by the  
array controller 94, and is used to weight the aperture to  
reduce the aperture sidelobe levels. The attenuator 28  
can also be used for power management.

10 The array system further comprises N aperture  
partitioning selectors 40, each coupled to selector port  
34 of a corresponding module 20. Each selector 40 com-  
prises an M-way power divider/combiner device 42 having M  
device ports, respectively coupled through a programmable  
phase shifter and variable attenuator to a corresponding  
one of the M RF switches. For the embodiment shown in  
15 FIG. 1, the index M is chosen as three, so that each  
partitioning selector 40 comprises a three-way power  
divider/combiner 42 with three device ports 42A, 42B, 42C,  
three attenuators 45A, 45B, 45C, three phase shifters 43A,  
43B, 43C, and three RF switches 44, 46, 48, all indepen-  
20 dently controllable by the array controller 94.

The array controller 94 preferably comprises a  
digital computer which is interfaced to the various  
elements it controls, such as the various RF switches, the  
variable attenuators and the beam steering phase shifters.

25 Each of the RF switches 44, 46 and 48 provides the  
capability of switching between an "off" position and an  
"on" position. When in the "off" position, each of the RF  
switches 44, 46 and 48 provides a matched load (not shown  
in FIG. 1) to both the "on" and the "off" ports of the  
30 corresponding RF switch. The RF switches 44, 46 and 48,  
therefore, provide a means for selectively connecting the  
respective device ports 42A, 42B, 42C to a corresponding  
partition port 46A, 46B, 46C of the selector 40. Each  
partition port 46A, 46B, 46C is connected to a correspond-  
35 ing one of the N selector ports 51A<sub>i</sub>, 61B<sub>i</sub> and 71C<sub>i</sub> of the

1 M manifold apparatus, in this embodiment the A, B or C  
manifold apparatus 50, 60 or 70.

5 The output of each of the three RF switches 44, 46  
48 at the respective partition port 46A, 46B, 46C is  
summed at the corresponding manifold apparatus 50, 60 or  
70 with the outputs from the corresponding RF switch of  
each of the other aperture partitioning selectors 40 com-  
prising the array system. Thus, as shown in FIG. 1, the  
respective outputs  $A_i$  from the RF switches 44 are summed  
10 at the "A" manifold apparatus 50, the respective outputs  
 $B_i$  are summed at the "B" manifold apparatus 60, and the  
outputs  $C_i$  from the RF switches 48 are summed at the "C"  
manifold apparatus 70. If the index M were greater than  
15 three, e.g., 5, then the selector 40 would include two  
additional attenuators, phase shifters, and RF switches,  
the divider/combiner 42 would be a five-way device, and  
there would be two additional manifold apparatus (not  
shown), the "D" manifold apparatus and the "E" manifold  
apparatus.

20 In the embodiment of FIG. 1, each of the manifold  
apparatus 50, 60 and 70 comprises an N selector port by  
two network port manifold network 52, 62, 72, and a magic  
T coupler 57, 67, 77. The N selector ports of the respec-  
tive manifold networks 52, 62, 72 are connected to the  
25 respective RF switch 44, 46 or 48 of each partitioning  
selector 40, and the two network ports are connected to  
the sidearm ports of the respective magic T coupler 57, 67  
or 77.

30 Each of the manifold networks 52, 62 and 72 are  
typically constructed of two uniform corporate networks  
such as are well known to those skilled in the art, acting  
as uniformly weighted power combiner/divider circuits. In  
the receive mode, the manifold networks 52, 62, 72 are  
constructed to separately sum the signals at the first N/2  
35 selector ports and the signals at the latter N/2 selector

1 ports, and to provide the respective partial sums at the  
respective X and Y network ports to be coupled to the  
respective sidearm ports of the respective Magic T coupler  
57, 67 or 77. For example, manifold network 52 is adapted  
5 to sum the selector signals  $A_i$ ,  $i=1$  to  $N/2$ , and to provide  
the resulting partial sum at port 53X, and to sum the  
signal  $A_i$ ,  $i=N/2 + 1$  to  $N$ , to provide the resulting and  
partial sum at port 53Y. In the transmit mode, the  
excitation signals applied at the respective X and Y ports  
10 of the manifold networks 52, 62, 72 are each divided into  
 $N/2$  signals of equal amplitude and phase to be supplied to  
the corresponding RF switches 44, 46, 48 of the respective  
 $N/2$  aperture partitioning selectors 40.

Magic T coupler devices 57, 67 and 77 are well known  
15 in the art and are described, for example, in "Microwave  
Antenna Theory and Design," edited by Samuel Silver, 1965,  
1949, Dover Publications, at page 572. In the receiver  
mode, the sum of the two partial sum signals at ports 53X  
and 53Y, i.e., the sum of the signals  $A_i$ ,  $i=1$  to  $N$ , will  
20 appear at the sum port 57X of the Magic T coupler 57 with  
the power at the difference port 56Y being essentially  
zero. The respective sum ports 57X, 67X and 77X of the  
Magic T couplers 57, 67 and 77 are then coupled to the  
receiver 92 for signal processing. Each output at the  
25 respective ports 57X, 67X and 77X represents the corre-  
sponding array subaperture output resulting from an  
arbitrary partition of the array formed by the positions  
of the corresponding RF switches 44, 46 and 48.

The difference ports 57Y, 67Y and 77Y of the Magic T  
30 couplers 57, 67 and 77 are connected to respective A, B  
and C excitation signal sources, in this case represented  
by excitation frequency synthesizer 90.

In the transmit mode, the excitation signal applied  
at the difference port 57Y is divided into two signals, of  
35 equal amplitude and phase, at the sidearm ports 56X and

1        56Y, which are in turn divided by the manifold network 52  
into N selector port excitation signals, of equal ampli-  
tude and phase, to be supplied to the corresponding RF  
switches 44 of the respective aperture partitioning  
5        selectors 40. Similar functions are provided by the  
manifold networks 62 and 72. The RF switches 44 select  
the appropriate module for the excitation. For example,  
10      an excitation signal "A" applied at port 57Y will be  
supplied to the RF switches 44 of the N aperture parti-  
tioning selectors 40. For those modules to be employed in  
the transmit mode for the A excitation signal, switch 44  
will be set to the "on" position. The A signal component  
15      may be combined with the B and C excitation signal compo-  
nents, if RF switches 46 and 48 are also switched to the  
"on" position.

The array system described with respect to FIG. 1  
provides a means for arbitrary partitioning of the array  
aperture formed by the N radiative elements 15 comprising  
20      the system. The three RF switches 44, 46 and 48 compris-  
ing the aperture partitioning selector 40 provide arbit-  
rary aperture partitioning on receive as well as on  
transmit. The position of each switch determines the size  
25      and configuration of each partition. On reception, the  
position of each switch does not affect the outputs of the  
other two switches; therefore, partitions can overlap  
during this mode of operation. Since the array feed is  
not divided into quadrants, full roll stabilization is  
realizable for any arbitrary partitioning, as will be  
30      described more fully below. On transmission, overlapping  
partitions are also possible if the power amplifier 24 of  
modules 20 is operated in the linear mode.

1        The provision of the beam steering phase shifters  
43A-C and variable attenuators 45A-C in each channel of  
the partition selector provides the capability of indepen-  
5        dently steering or amplitude weighting the beam or pattern  
formed by each sub-aperture. If these phase shifters and  
variable attenuators are employed in the aperture parti-  
tioning selector 40, then the phase shifter 32 and vari-  
able attenuator 28 in the module 20 are unnecessary. The  
10      phase shifters 43A-C and attenuators 45A-C could, of  
course, be omitted from the selectors 40 if the flexibil-  
ity provided by these elements is unnecessary; in this  
case the module phase shifter 32 and attenuator 28 may be  
employed to steer and shape the beam.

15      With the phase shifters 43A-C, three independent  
apertures may be formed with three independently steerable  
beams, which on transmit may be excited by three indepen-  
dent exciter signals generated by synthesizer 90. There  
is another advantageous function which may be implemented  
using the M exciter signals, to provide extended bandwidth  
20      capability for off-broadside beams for very large aper-  
tures. For such large apertures, the relatively large  
spacing between the radiative elements 15 on opposite  
sides of the aperture can serve to destroy the additive  
effects on signals from the spaced elements on an off-  
25      broadside target for very short duration impulse trans-  
missions, i.e., having a wide bandwidth, so that the array  
beams are effectively limited to the broadside direction.  
To correct for the differences in range from the spaced  
aperture elements to the target, the aperture may be  
30      partitioned into M contiguous non-overlapping subaper-  
tures, each driven by a delayed version of the same  
excitation signal. Depending on the beam position, the  
respective exciter signals are respectively delayed by  
some predetermined time period needed to correct for the  
35      range difference between the target and the radiative

elements 15 in the respective sub-apertures. Thus, if the aperture is divided into subapertures A, B, C, with aperture C closest to the target located in the off-broadside beam, then the exciter signal driving aperture A, the subaperture furthest from the target, will not be delayed at all; the exciter signal driving aperture B will be delayed by some period T, and the exciter signal driving aperture C will be delayed by some period 2T, and T being a function of the beam angle and the aperture size. In a similar manner, the large-sized aperture may be divided into three contiguous sub-apertures on receive, as on transmit, and the summed components at ports 57X, 67X and 77X, respectively, may be delayed by receiver 92 by appropriate respective delays to correct for the range difference between the respective subaperture radiative elements and the off-broadside target.

Several specific examples of exemplary aperture partitioning readily achievable by the system described with respect to FIG. 1 are now described.

20 Simultaneous Sum, Azimuth Difference and Elevation  
Difference Patterns

As is well known in the art, many radar systems employ two or more displaced radiating/receive elements (or groups of elements) so that each receives the signal from a point source at a slightly different phase. The received signals from each receive element (or group) are summed to form the array sum signal, and the received signal from one element (or group) is subtracted from the signal received on the other element (or group) to form a difference signal. The difference signal is a measure of the relative location of the target from the array boresight, since the difference signal will be nulled if the boresight is perfectly aligned on the target.

Difference signals are typically provided with respect to the azimuth and elevation null planes. Thus,

1       the azimuth difference signal indicates the angular offset  
of the boresight from the target with respect to the  
azimuth null plane, with the sign of the signal indicating  
the direction of the offset. Similarly, the magnitude and  
5       sign of the elevation difference signal indicates the  
angular offset of the boresight from the target with  
respect to the orthogonal elevation null plane.

10      The array system described with respect to FIG. 1  
with the index  $M=3$  can be employed to divide the array  
system radiative array aperture into three or less sub-  
apertures. FIG. 2 is a functional diagram for dividing an  
exemplary circular aperture, i.e., where the  $N$  radiative  
elements 15 are distributed throughout the area circum-  
scribed by a circle, into four quadrants for generating  
15     simultaneous sum, azimuth difference and azimuth elevation  
signals. In this example, the radiative elements of the  
array system are arranged in four quadrants I to IV,  
defined by the azimuth null plane and the elevation null  
plane.

20      To form the azimuth difference signal, the combined  
contributions from the signals received by the radiating  
elements quadrants II and IV are subtracted from the  
combined signals received by the radiating elements in  
quadrants I and III. The elevation difference signal is  
25     provided by subtracting the combined signals received at  
the radiating elements in quadrants III and IV from the  
combined signals received at the elements in quadrants I  
and II. To configure the system to provide simultaneous  
sum, difference azimuth and difference elevation patterns,  
30     the respective positions of the A, B and C RF switches 44,  
46 and 48 of the modules associated with radiative ele-  
ments in the respective quadrants are shown in FIG. 2.  
Thus, for those partition selectors 40 connected to  
modules 20 connected to radiative elements 15 in quadrant  
35     I, the A and C switches are positioned to the "off"

1 position, and the B switches are positioned to the "on" position. For the partition selectors 40 coupled to modules 20 and radiative elements 15 in quadrant II, the A switches are positioned to the "on" position, and the B and C switches are positioned to the "off" position. For those partition selectors 40 associated with modules 20 and radiative elements 15 in quadrant III, the A switches are positioned to the "off" position, and the switches B and C are positioned to the "on" position. For those partition selectors 40 associated with modules 20 and radiative elements 15 in quadrant IV the A and C switches are positioned to the "on" position, and the B switches are positioned to the "off" position. The three manifold apparatus outputs on reception are

15

$$\Sigma_A = (\text{Quad II}) + (\text{Quad IV})$$

$$\Sigma_B = (\text{Quad I}) + (\text{Quad III})$$

20

$$\Sigma_C = (\text{Quad III}) + (\text{Quad IV})$$

from which

$$\Sigma = (\text{Quad I}) + (\text{Quad II}) + (\text{Quad III}) + (\text{Quad IV})$$

25

$$= \Sigma_A + \Sigma_B$$

$$\Delta AZ = [(\text{Quad I}) + (\text{Quad III})] - [(\text{Quad II}) + (\text{Quad IV})]$$

30

$$= \Sigma_B - \Sigma_A$$

$$\Delta EL = [(\text{Quad I}) + (\text{Quad II})] - [(\text{Quad III}) + (\text{Quad IV})]$$

1                    $= \Sigma - 2 [(\text{Quad III}) + (\text{Quad IV})]$

$= \Sigma - 2 \Sigma_c$

5                    $= \Sigma_A + \Sigma_B - 2 \Sigma_c$

The invention provides a means of arbitrarily assigning a particular radiating element to a particular quadrant of the array without requiring changes in hard wired connections or complex signal processing. The array controller is provided with attitude position data, e.g., from the aircraft inertial platform 98 in the case of an aircraft-mounted active array. This data may be used to direct the aperture partitioning selectors 40 to adjust the respective module RF switches to the correct state for the particular array roll angle.

This may be appreciated with reference to FIG. 3. Assume that the array reference plane is initially aligned with azimuth plane 210. The switch positions of the aperture partitioning selectors 40 are as shown in FIG. 2. Now assume that the array rolls to a 30 degree angle with respect to the azimuth plane, such that the array reference planes are aligned with phantom lines 220 and 230 shown in FIG. 3. To roll stabilize the array with the horizon, the quadrant positions of certain of the radiative elements 15 are reassigned. Thus, the radiative elements 15 located in the cross-hatched sector 222, nominally in quadrant II for the case when the aircraft is aligned with the horizon, are reassigned to quadrant I, i.e., the roll stabilized or "new" quadrant I is the former or "old" quadrant I minus the elements 15 in cross-hatched sector 228 plus the elements in cross-hatched sector 222. Similarly, the radiative elements in sector 224, nominally in quadrant IV, are reassigned to quadrant II. The radiative elements in sector 226,

1 formerly in quadrant III, are reassigned to quadrant IV.  
The radiative elements in sector 228, formerly in quadrant  
I, are reassigned to quadrant I.

5 To implement the reassignment of radiative elements  
requires only that the positions of the RF switches of the  
aperture partitioning selectors 40 associated with the  
radiative elements 15 whose respective quadrant positions  
are realigned be adjusted to conform to the states de-  
scribed in FIG. 3 for the respective new quadrants. The  
10 array controller 94 may effect this adjustment rapidly, so  
that the azimuth and elevation difference patterns may be  
electronically roll stabilized, without the need for  
mechanical roll gimbals or complex signal processing.

15 The system of FIG. 1 provides a means for roll  
stabilizing the aperture partitioning of the array with  
respect to rotation of the array relative to a prede-  
termined reference plane, such as plane 210 in FIG. 3.  
The array may be assumed to have an array reference plane,  
such as plane 230 in FIG. 3. The radiative-element-to-  
20 sub-aperture connections for the initial or first roll  
position state may be stored in memory by the array  
controller. To compensate for rotation of the array to a  
particular roll angle relative to the initial position  
state, the array reference plane 230 is assumed to have  
25 rotated by the particular roll angle relative to the  
reference plane 210, and the positions of the radiative  
elements (and associated module 20 and aperture partition-  
ing selector 40) relative to the reference plane associ-  
ated with the initial pre-roll state are mapped into the  
30 same corresponding positions relative to the new position  
of the array reference plane.

1 Adaptive Nulling

FIG. 4 shows a functional description of the positions of the RF switches of the aperture partitioning selectors 40 to generate an auxiliary aperture for adaptive nulling and simultaneous sum ( $\Sigma$ ) and azimuth difference ( $\Delta AZ$ ) with a circular aperture. Alternatively, the elevation difference pattern could be generated instead of the azimuth difference pattern. Other combinations are possible, e.g., a communication aperture with two auxiliary apertures. The three manifold apparatus outputs resulting from the configuration shown in FIG. 4 are

$$L = \Sigma_A$$

$$15 \quad R = \Sigma_B$$

$$AUX = \Sigma_C$$

from which

$$20 \quad \Sigma = \Sigma_A + \Sigma_B$$

$$\Delta AZ = \Sigma_A - \Sigma_B$$

$$25 \quad \text{Auxiliary} = \Sigma_C$$

Overlapping partitions

FIGS. 5A and 5B describe the positioning of the RF switches of the aperture partitioning selectors 40 to obtain two possible aperture partitions with overlap. As illustrated by the two exemplary partitions in FIGS. 5A and 5B, the three regions A, B, and C can take any arbitrary configuration. As will be appreciated by those skilled in the art, the overlapping apertures shown in

1 FIG. 5A may be necessary in some radar applications for  
detection and location of slowly moving targets.

5 In the case illustrated in FIG. 5B, aperture A comprises the entire area of the circular aperture of radius  $r_A$ , aperture B comprises the area within the intermediate circle of radius  $r_B$ , and aperture C comprises the area within the inner circle of radius  $r_C$ . The apertures are independent, and their beam may be scanned and shaped (by the respective pairs of phase shifters and  
10 attenuators comprising partitioning selector 40) independently of each other. The three aperture outputs are

$$A = \Sigma_A$$

15  $B = \Sigma_B$

$$C = \Sigma_C$$

One advantage of the embodiment shown in FIG. 1 is  
20 that the aperture partition selector 40 may be located outside the corresponding module 20, allowing the array system to be implemented with N universal modules. The additional elements needed to provide the increase in aperture complexity are located outside the module. Since  
25 not all applications require the additional complexity, the same modules 20 may be used for all applications. For example, an active array antenna with roll stabilization for a two-way monopulse radar requires at least two apertures ( $M = 2$  or greater); on the other hand, a half-duplex communication system needs only a single aperture  
30 ( $M=1$ ).

Higher order partitioning can be obtained by increasing the number of outputs from the aperture partitioning selector 40, i.e., increasing M. If a particular partition is always limited to a certain physical area of  
35

1       the aperture, then the corresponding manifold is required  
to sum only those signals from manifolds lying in the  
desired area. For example, if a guard aperture formed by  
5       four preselected radiative elements is required, then only  
the corresponding four module outputs need to be summed;  
this will require only a four input manifold.

10      While the invention has been described with respect  
to a circular array aperture, it may readily be practiced  
with arrays having other configurations, e.g., rectangular  
or trapezoidal.

15      A multifunction active array system has been de-  
scribed which is capable of providing a number of useful  
features. For example, the array system aperture can be  
partitioned into M or fewer subapertures, which can  
overlap. The aperture partitioning on transmit and on  
receive can differ in any arbitrary manner. Each subaper-  
ture can transmit and receive at different frequencies  
and/or scan angles. For M=3 the array system can be used  
20      to provide simultaneous sum, azimuth difference and  
elevation difference patterns to provide a subaperture for  
adaptive nulling, with simultaneous sum and azimuth (or  
elevation) difference patterns or a simultaneous sum  
pattern with a guard aperture. With the capability for  
multiple independent transmit apertures, the system  
25      further provides off-broadside expanded bandwidth capabil-  
ities for large apertures. The system further provides  
the capability for electronic roll stabilization for all  
modes of operation.

30      The invention is not limited to active array sys-  
tems, but may also be employed with passive array systems  
which do not employ active modules. In the case of a  
passive array system, the modules 20 shown in FIG. 1 are  
eliminated, and the aperture partitioning selectors 40 are  
connected directly to the respective radiative elements

1        15. Alternatively, the modules 20 could consist of only  
the attenuator 28 and phase shifter 32. Arbitrary  
aperture partitioning is available in this case as well.

5        It is understood that the above-described embodiment  
is merely illustrative of the possible specific embodiments  
which may represent principles of the present  
invention. Other arrangements may be devised in accordance  
with these principles by those skilled in the art  
without departing from the scope of the invention.

10

15

20

25

30

35

CLAIMSWhat is claimed is:

1. An array system for providing a plurality of array subapertures, comprising:
  - an array of N spaced radiative elements forming a radiative aperture;
  - N aperture partitioning selector devices respectively coupled one to a respective radiative element for dividing said radiative aperture into M or fewer subapertures, comprising:
    - an M-way power divider device having M device ports and a radiative element port coupled to said radiative element, said divider device adapted to divide the power of signals received at said radiative element into M component signals of substantially equal power at said device ports; and
    - means for selectively connecting said respective device ports of said power divider device to a corresponding partition port of said selector device;
  - M manifold apparatus having N manifold ports, each of said ports respectively connected to a corresponding partition port of said N aperture partitioning selectors, said manifold apparatus comprising means for combining the respective component signals at said corresponding partition ports of said N selector devices and providing a respective subaperture signal at an output port of each of said M manifold apparatus;
  - an array system controller coupled to said selector devices for controlling said means for selectively connecting said device ports to control

35

the partitioning of said aperture into M or fewer subapertures, each subaperture comprising the radiative elements selectively connected to said respective manifold apparatus; and

a receiver responsive to said M subaperture signals to provide a selected partitioned aperture function.

2. The array system of Claim 1 wherein said respective manifold apparatus comprises a uniform corporate network.

5

3. The array system of Claim 1 wherein said means for selectively connecting said respective device ports to a corresponding partition port of said selector comprises M RF switches respectively selectively coupling a respective device port to a corresponding partition port.

5

4. The array system of Claim 1 wherein said means for selectively connecting said respective device ports of said power divider device to a corresponding selector port further comprises means for programmably phase shifting the respective electrical signals coupled between said respective device ports and said corresponding selector port, said phase shifting means being controlled by said system controller to steer the corresponding sub-aperture array beam to a desired direction.

5

5. The array system of Claim 1 wherein said means for selectively connecting said respective device ports of said power divider device to a corresponding selector port further comprises means for programmably attenuating the respective electrical signals coupled between said respective device ports and said corresponding selector port, said attenuating means being controlled by said system

controller to achieve a desired amplitude weighting of the sub-aperture radiative elements.

6. The array system of Claim 1 wherein further comprising means for roll stabilizing the respective array sub-apertures, comprising:

means for providing a roll signal indicative of the rotational position of an array reference plane of said array relative to a predetermined reference plane; and

wherein said array controller further comprises means responsive to said roll signal to control the means for selectively connecting said respective device ports to a corresponding partition port so as to adjust the connection of the radiative elements to particular sub-apertures to correct for the rolling of said aperture relative to said reference plane.

7. An active array system for providing a plurality of array subapertures, comprising:

an array of N spaced radiative elements forming a radiative aperture;

N active modules respectively coupled one to each radiative element, said modules comprising a receive channel comprising a low noise amplifier coupled to said corresponding radiative element for amplifying signals received at said corresponding radiative elements and providing said amplified receive signals at a module selector port;

N aperture partitioning selector devices respectively coupled one to a selector port of each module for dividing said radiative aperture into M or fewer subapertures, comprising:

an M-way power divider device having M device ports and a module port coupled to said selector port of said module, said divider device adapted to divide the power of said amplified receive signals at said module port into M component signals of substantially equal power at said device ports; and

20

means for selectively connecting said respective device ports of said power divider device to a corresponding partition port of said selector;

25

30

M manifold apparatus having N manifold ports, each of said ports respectively connected to a corresponding partition port of said N aperture partitioning selectors, said manifold apparatus comprising means for combining the respective component signals at said corresponding partition ports of said N aperture partitioning selectors and providing a respective subaperture signal at an output port of each of said M manifold apparatus;

35

40

an array system controller coupled to said aperture partition selectors for controlling said means for selectively connecting said device ports to control the partitioning of said aperture into M or fewer subapertures, each subaperture comprising the radiative elements and associated modules connected to said respective manifold apparatus; and

45

a receiver responsive to said M subaperture signals to provide a selected partitioned aperture function.

8. The array system of Claim 7 wherein said respective manifold apparatus comprises a uniform corporate network.

9. The array system of Claim 7 wherein said means for selectively connecting said respective device ports to a corresponding partition port of said selector comprises M RF switches respectively selectively coupling a respective device port to a corresponding partition port.

10. The array system of Claim 7 wherein said means for selectively connecting said respective device ports of said power divider device to a corresponding selector port further comprises means for programmably phase shifting the respective electrical signals coupled between said respective device ports and said corresponding selector port, said phase shifting means being controlled by said system controller to steer the corresponding sub-aperture array beam to a desired direction.

11. The array system of Claim 7 wherein said means for selectively connecting said respective device ports of said power divider device to a corresponding selector port further comprises means for programmably attenuating the respective electrical signals coupled between said respective device ports and said corresponding selector port, said attenuating means being controlled by said system controller to achieve a desired weighting of the sub-aperture radiative elements to reduce the beam sidelobe level.

12. The array system of Claim 7 wherein further comprising means for roll stabilizing the respective array sub-apertures, comprising:

means for providing a roll signal indicative of the rotational position of an array reference plane of said array relative to a predetermined reference plane; and

wherein said array controller further comprises  
means responsive to said roll signal to control the  
means for selectively connecting said respective  
device ports to a corresponding partition port so as  
to adjust the connection of the radiative elements  
to particular sub-apertures to correct for the  
rolling of said aperture relative to said reference  
plane.

13. A multifunction active array system for providing a plurality of arbitrary array subapertures, comprising:

an array of  $N$  spaced radiative elements forming  
a radiative aperture;

5            $N$  active modules respectively coupled one to  
each radiative element, said module comprising a  
transmit channel comprising a transmit amplifier for  
amplifying excitation signals and a receive channel  
comprising a low noise amplifier for amplifying  
10          signals received at said corresponding radiative  
element, and means for coupling either said transmit  
channel or said receive channel to said radiative  
element;

15          an excitation signal source for generating one  
or more excitation signals;

a plurality of aperture partitioning selectors  
coupled one to a selector port of each module for  
dividing said radiative aperture into  $M$  or fewer  
20          subapertures, each selector comprising:

an  $M$ -way power divider/combiner device having  
 $M$  device ports and a module port coupled to  
said selector port of said corresponding  
module; and

25 means for selectively connecting said respective device ports of said power divider/-combiner device to a corresponding partition port of said selector;

30 M manifold apparatus having N manifold ports, each of said ports respectively connected to a corresponding partition port of said N aperture partitioning selectors, said manifold apparatus arranged to combine signals at said partition ports of the N modules and provide a combined subaperture signal at a combiner output of said manifold apparatus in a receive mode, said manifold apparatus being further arranged to divide an excitation input signal into N excitation module signals at said N ports of said manifold apparatus in a transmit mode;

35 and

40 an array system controller coupled to said aperture partition selector and said modules for controlling said means for selectively connecting said device ports to control the partitioning of said aperture into M or fewer subapertures and to select either the receive channel or the transmit channel of said module.

45 14. The array system of Claim 13 wherein said means for coupling either said transmit channel or said receive channel comprises a first RF switch for selectively connecting either the output of said transmit amplifier or the input of said low noise amplifier to said radiative element.

5 15. The array system of Claim 14 wherein said means for coupling either said transmit channel or said receive channel of said respective modules further comprises a

5 second RF switch for selectively coupling said module selector port to either the input of said transmit amplifier or the output of said low noise amplifier.

16. The array system of Claim 15 wherein said modules each further comprise a beam steering phase shifter coupled between said second RF switch, said phase shifter controlled by said array controller for steering 5 an array beam formed by said array in a desired direction.

17. The array system of Claim 16 wherein said modules each further comprise a variable RF attenuator coupled between said second RF switch and said selector port of said module, said variable attenuator controlled by said array controller for weighting the contributions 5 to the array beam from the corresponding radiative element.

18. The array system of Claim 13 wherein said means for selectively connecting said respective device ports to a corresponding partition port of said selector comprises M RF switches respectively selectively coupling a respective device port to a corresponding partition port. 5

19. The array system of Claim 13 wherein said means for selectively connecting said respective device ports of said power divider/combiner device to a corresponding selector port further comprises means for programmably phase shifting the respective electrical signals between said respective device ports and said corresponding selector port, said phase shifting means being controlled by said system controller to steer the corresponding sub-aperture beam to a desired direction. 5

20. The array system of Claim 13 wherein said means for selectively connecting said respective device ports of said power divider/combiner device to a corresponding selector port further comprises means for programmably attenuating the respective electrical signals coupled between said respective device ports and said corresponding selector port, said attenuating means controlled by said system controller to achieve a desired weighting of the sub-aperture radiative elements to reduce the beam  
5 sidelobe level.  
10

- 1 / 4 -

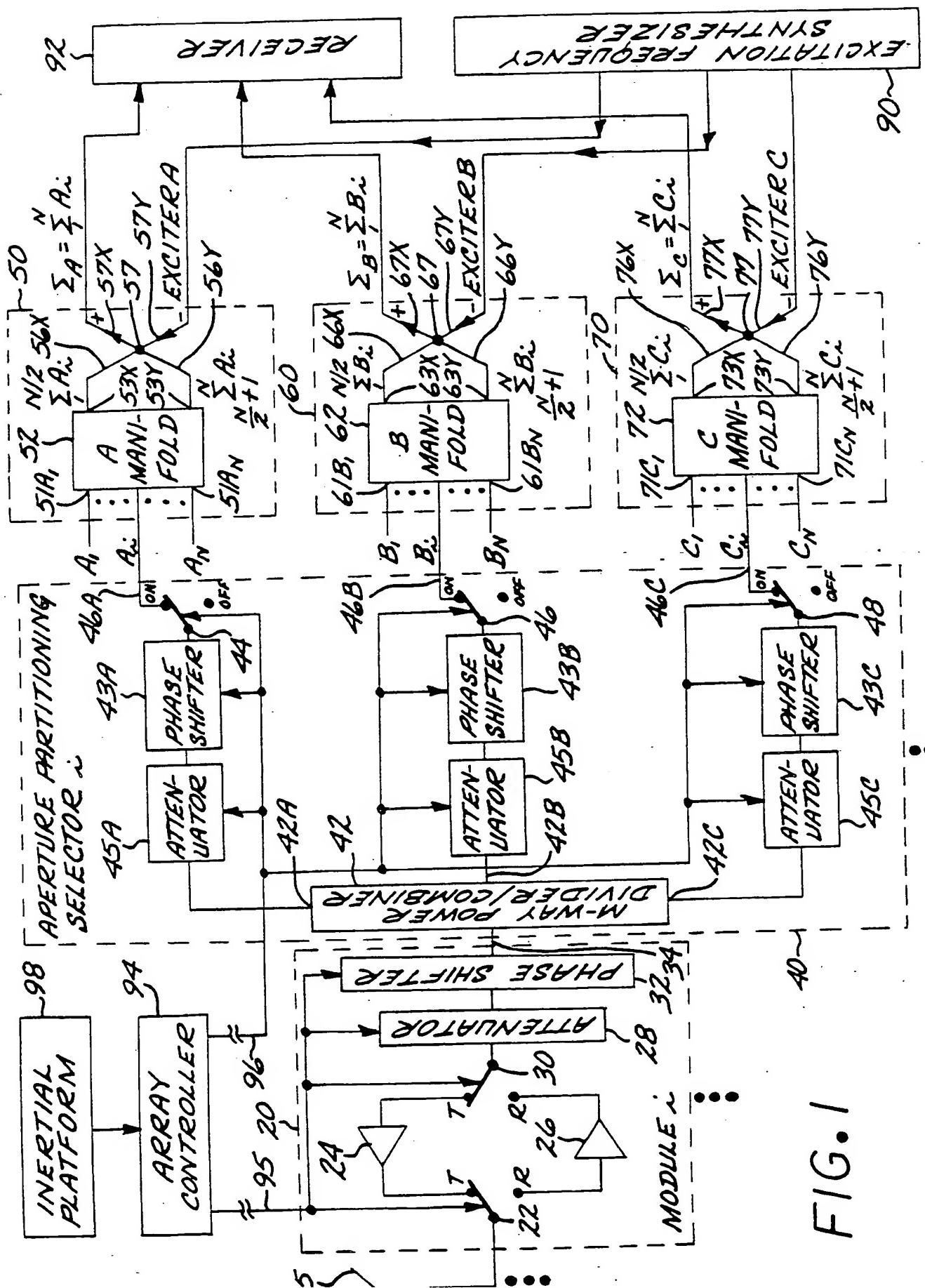
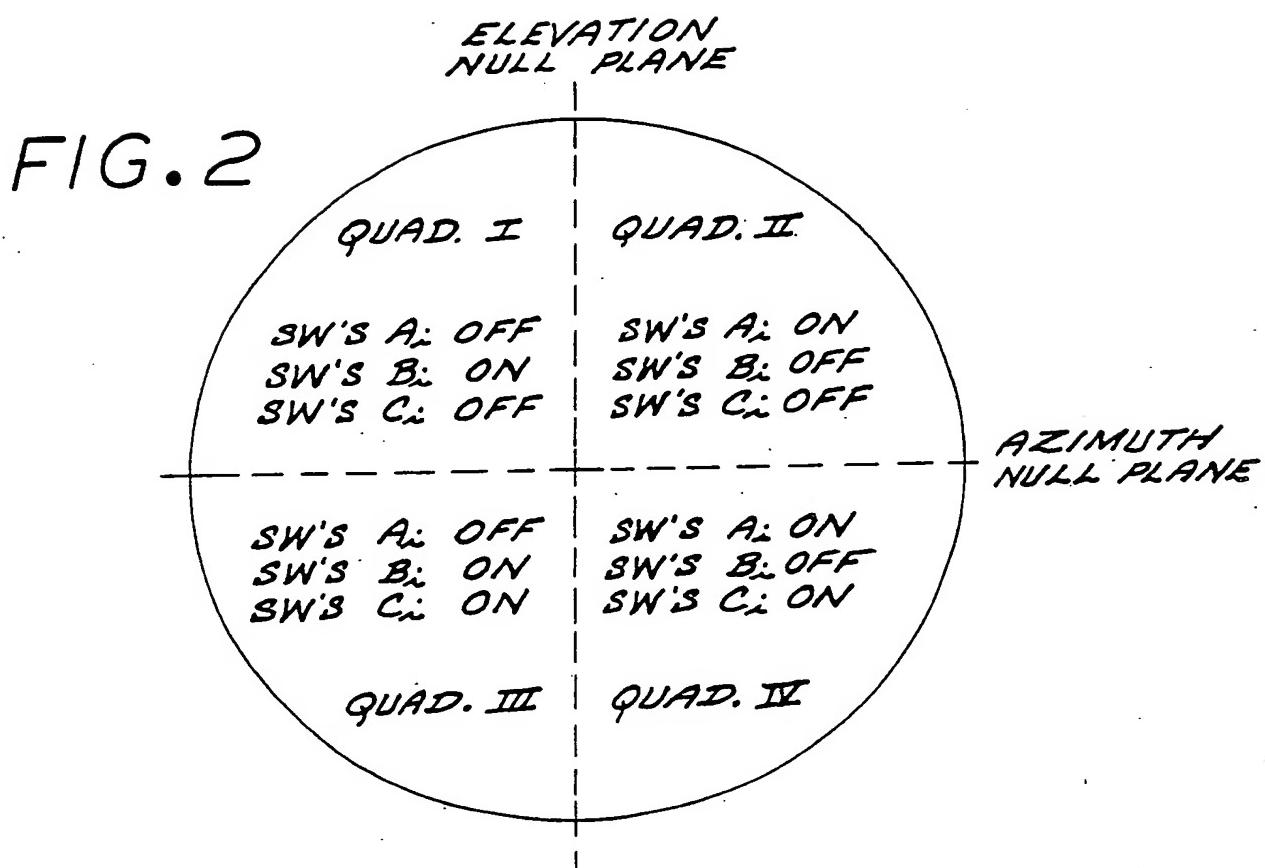
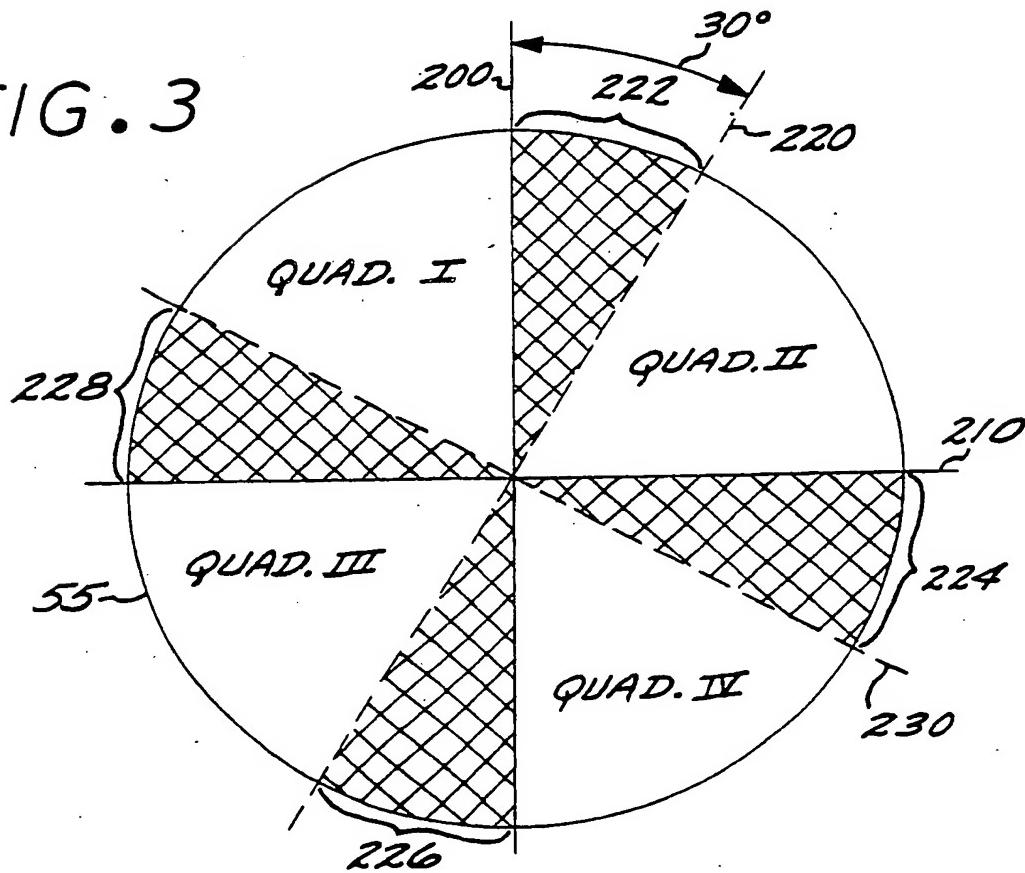


FIG. 1

- 214 -

**FIG. 3**

- 3 / 4 -

FIG. 4

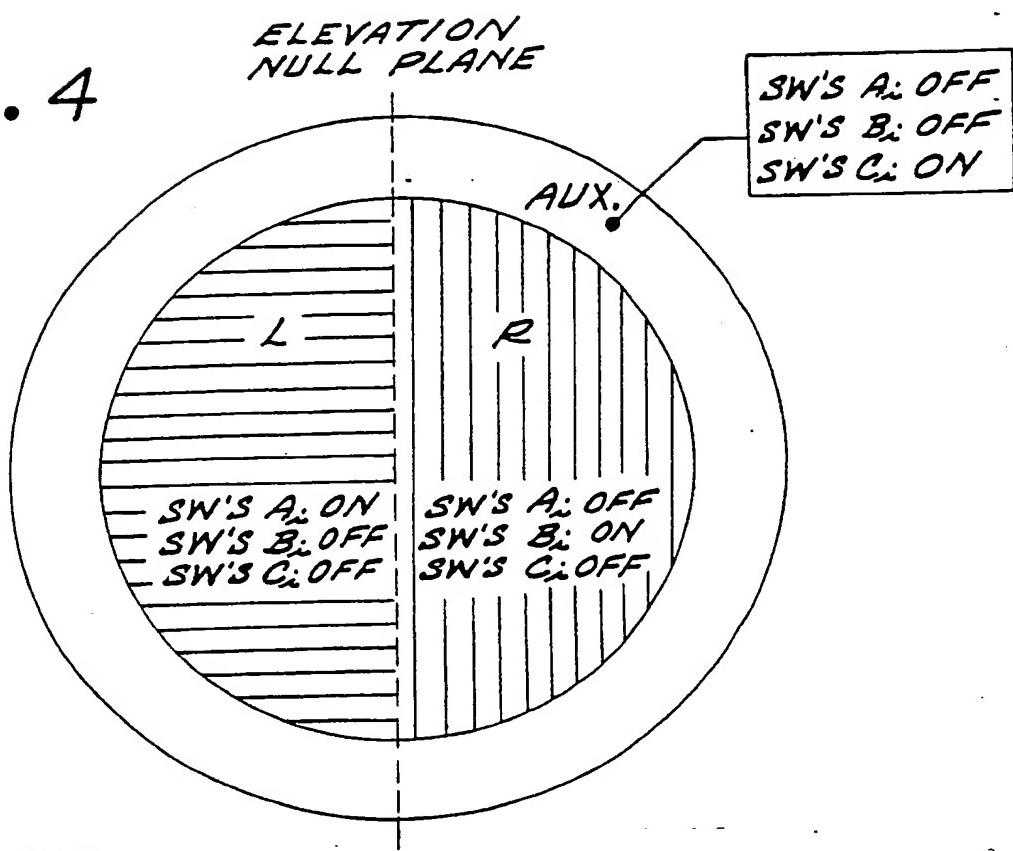
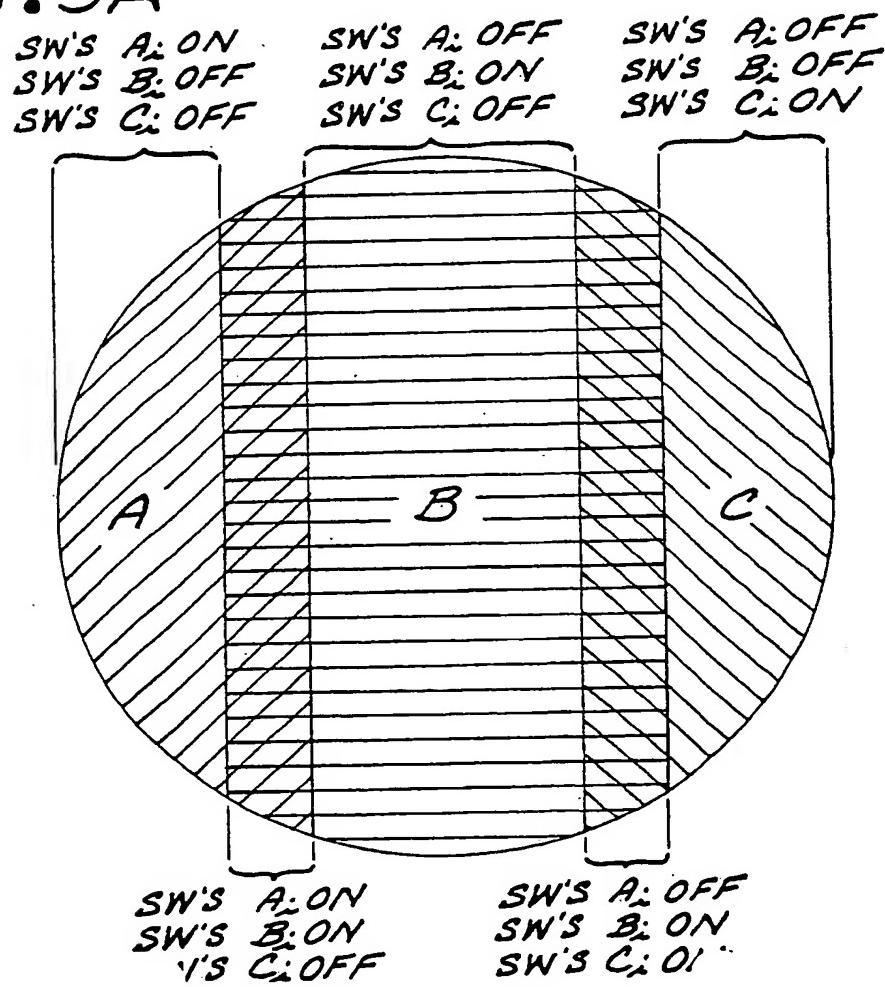
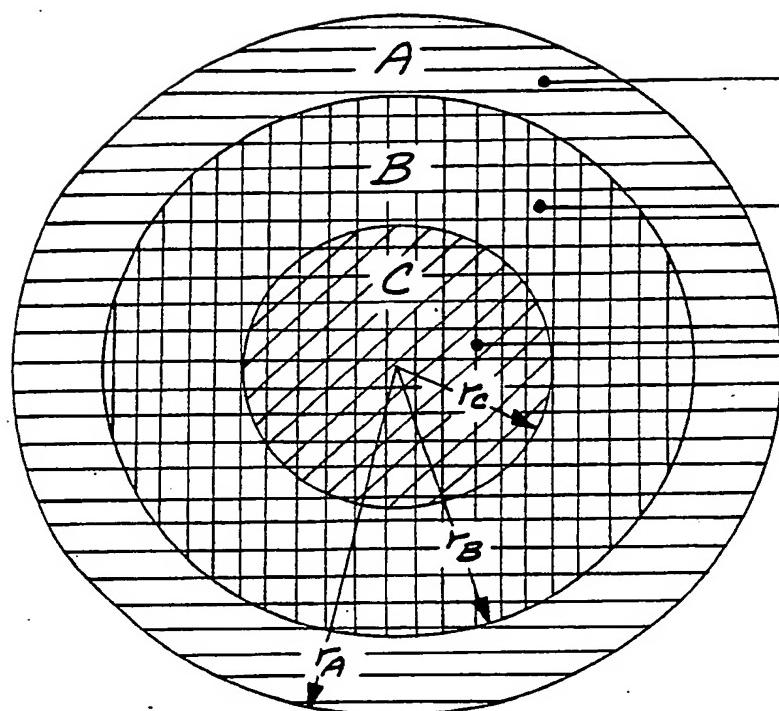


FIG. 5A



- 4 / 4 -



SW'S A<sub>i</sub> ON  
SW'S B<sub>i</sub> OFF  
SW'S C<sub>i</sub> OFF

SW'S A<sub>i</sub> ON  
SW'S B<sub>i</sub> ON  
SW'S C<sub>i</sub> OFF

SW'S A<sub>i</sub> ON  
SW'S B<sub>i</sub> ON  
SW'S C<sub>i</sub> ON

FIG. 5B

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 88/01319

## I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)<sup>6</sup>

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC<sup>4</sup>: H 01 Q 25/00; H 01 Q 3/24; H 01 Q 3/26

## II. FIELDS SEARCHED

Minimum Documentation Searched<sup>7</sup>

Classification System	Classification Symbols
IPC <sup>4</sup>	H 01 Q

Documentation Searched other than Minimum Documentation  
to the Extent that such Documents are Included in the Fields Searched<sup>8</sup>

## III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup>

Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	GB, A, 2018034 (SIEMENS) 10 October 1979 see the whole document --	1-3, 7-9, 13, 18
X	L'Onde Electrique, volume 65, no. 1, January-February 1985, (Paris, FR), G. Dubost et al.: "Réseau plat à commutation électronique de faisceaux dans la bande des 12 GHz", pages 56-61 see figures 1,2; paragraphs 2,3 --	1, 2, 7, 8
A	Patent Abstracts of Japan, volume 10, no. 370 (E-463)(2427), 10 December 1986, & JP, A, 61164302 (NIPPON TELEGR. & TELEPH. CORP.) 25 July 1986 --	1, 3, 4
A	US, A, 3965475 (L.F. DEERKOSKI et al.) 22 June 1976 see the whole document --	1
A	US, A, 4532519 (R.M. RUDISH et al.) 30 July 1985 --	1, 3, 4, 6 . / .

- \* Special categories of cited documents: <sup>10</sup>
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "Z" document member of the same patent family

## IV. CERTIFICATION

Date of the Actual Completion of the International Search  
29th August 1988

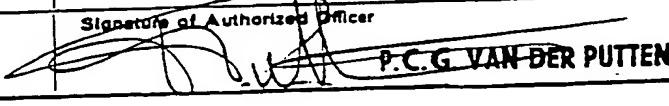
Date of Mailing of this International Search Report

20.09.88

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer



P.C.G. VAN DER PUTTEN

## III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	see figures 9-11; column 7, line 51 - column 10, line 21 --	
A	US, A, 3737899 (C.J. GEORGOPoulos) 5 June 1973 see the whole document --	1,4
A	US, A, 3750175 (R.M. LOCKERD et al.) 31 July 1973 see figures 3,5,10; column 2, lines 6-54; column 4, lines 26-51; column 10, line 31 - column 11, line 32 --	1,4,7,10, 13
A	US, A, 4257050 (G. PLOUSSIOS) 17 March 1981 --	
A	US, A, 3267472 (C. FINK) 16 August 1966 -----	

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.**

US 8801319  
SA 22351

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 13/09/88. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB-A- 2018034	10-10-79	NL-A- 7902530 BE-A- 875236 FR-A, B 2421479 DE-A, B, C 2813916 JP-A- 54134539 AU-A- 4562679 AU-B- 509462 US-A- 4286267	02-10-79 01-10-79 26-10-79 04-10-79 19-10-79 04-10-79 15-05-80 25-08-81
US-A- 3965475	22-06-76	None	
US-A- 4532519	30-07-85	None	
US-A- 3737899	05-06-73	None	
US-A- 3750175	31-07-73	NL-A- 6813136 FR-A- 1579889 US-A- 3553693 GB-A- 1232480 DE-A- 1791091	17-06-69 29-08-69 05-01-71 19-05-71 24-02-72
US-A- 4257050	17-03-81	None	
US-A- 3267472		None	